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PATENT SPECIFICATION

Convention Date (United States): June 12, 1937.

511,320

Application Date (in United Kingdom): June 11, 1938. No. 17366/38.

(Patent of Addition to No. 498,899: dated July 18, 1936.)

Complete Specification Accepted: Aug. 16, 1939.

COMPLETE SPECIFICATION

Improvements in Apparatus for Testing the Balance of Rotors

We, SPERRY GYROSCOPE COMPANY, INC., a company incorporated under the laws of the State of New York, United States of America, of Manhattan Bridge Plaza, Brooklyn, New York, United States of America, (Assignees of ORLAND E. ESVAL and CARL A. FRISCHE), do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to apparatus for determining the unbalance of a rotor, and is generally an improvement in or modification of the apparatus for that purpose which is the subject-matter of British Patent No. 498,899.

According to said prior specification apparatus for determining the unbalance of a rotor comprises electro-magnetic means sensitive to vibrations due to unbalance of the rotor (or to irregularity in a bearing in which it turns) and serving to produce an alternating E.M.F. corresponding to such vibrations, means for supplying an alternating E.M.F. of a frequency corresponding to the speed of the rotor, and indicating means arranged to be controlled in response to said E.M.F.'s and so to give the angular position and magnitude of the unbalanced weight in the rotor.

The present invention consists in an improvement in or modification of apparatus for determining the unbalance of a rotor, which is the subject-matter of British Patent No. 498,899 comprising means for selectively locking the rotor against the vibration at either of two points on the rotor axis, and means for measuring relative vibratory movements of the rotor axis about the point thus locked, by means of currents or voltages generated by such movements of the rotor or of a part associated therewith in a magnetic field.

The invention also consists in an improvement in or modification of apparatus for determining the unbalance of a rotor which is the subject-matter of British Patent No. 498,899, wherein the rotor is so mounted as to prevent one point of its axis from vibrating during the time the vibration of another point of its axis is measured electromagnetically by means of currents or voltages generated by movement of the rotor or of a part associated therewith in a magnetic field provided by a member having substantially circular symmetry about the rotational axis of the rotor.

The invention further consists in an improvement in or modification of apparatus for determining the unbalance of a rotor which is the subject-matter of British Patent No. 498,899 wherein the rotor bearing frame is so mounted that one point on the axis is locked against vibration and another point on the axis is allowed to perform conical oscillations about an axis through the locked point in a magnetic field, whereby measurements of such oscillations are made by means of the currents or voltages generated thereby.

In order that the present invention may be fully understood and carried into effect, one embodiment thereof will now be described with reference to the accompanying drawings, in which:—

Fig. 1 is a perspective view of apparatus in accordance with the present invention, showing a rotor mounted therein for balancing;

Fig. 2 is a partial plan view of the structure of Fig. 1;

Fig. 3 is a fragmentary sectional view taken along line 3—3 of Fig. 2, the springs in the correction planes being both locked preparatory to receiving a rotor in the apparatus for balancing;

Fig. 4 is a schematic plan view of the cam arrangement used for shifting the rotor frame supporting springs;

Fig. 5 is a vertical sectional view of a portion of the apparatus of Fig. 1 and shows the apparatus positioned for pivoting the rotor in the upper correction plane, as when determining the unbalanced moment in the lower correction plane;

Fig. 6 is a sectional view taken along line 6—6 of Fig. 2;

Fig. 7 is a schematic diagram of the apparatus and connected electrical circuits;

Fig. 8 is a schematic view, in elevation, of the pick-up unit; and

Fig. 9 is a sectional view taken along line 9—9 of Fig. 8.

Similar characters of reference are used in all of the above-mentioned figures to indicate corresponding parts.

The underlying theory of automatic balancing embodied in the apparatus of this invention is based on the fact that for a fixed rotor speed, the rotating deflection of the rotor shaft, rotor casing, etc., has a fixed angular or phase relation to the disturbing force or weight, the deflection being apparent as vibration. The motion resulting at each end of the rotor from dynamic unbalance of the rotor is approximately circular in a plane perpendicular to the rotor shaft. Thus, a particle at the end of the rotor axis moves in a circular path and this motion has a definite phase or angular relation to the unbalanced weight of the rotor, so that should the dynamic unbalance at one end of the rotor be advanced by a certain angle, the particle on the rotor axis will be correspondingly advanced by the same angle in its circular path. Two indications are necessary in dynamically balancing an end of a rotor, one indication being the magnitude, and the other the position of the unbalanced weight. The circular motion of the particle on the rotor axis provides the information which may be used to give both the position and magnitude of the unbalanced weight. At a given speed, the magnitude of the unbalance is directly proportional to the amplitude, i.e., to the diameter of the circular path in which the particle is moving.

In the apparatus of the present invention, an electromagnetic pick-up unit or vibration instrument with a ring type armature is employed, which has a very loose coupling with the rotor frame at the axis of the motor, two of these pick-up units being employed, one at each end of the rotor, to generate voltages proportional to the amplitude at a desired frequency. With the rotor pivoted at one end in a plane (first "correction plane") extending at right angles to the rotor axis at that end of the rotor, the voltage generated in the pick-up unit at the other end of the rotor is proportional to the moment of the unbalanced rotor weight in a second "correction plane," so that a voltmeter connected to the output of the pick-up unit will therefore indicate directly the degree of dynamic unbalance at such other end of the rotor or second "correction plane." The electromagnetic pick-up unit is designed so as to be sensitive to vibration in only one plane, and hence it generates voltage as though the motion of the particle were vibrating across the diameter of its circular path. By making the pick-up unit turnable, it can be positioned so as to generate voltage along any diameter of this path, and the value of the voltage output of all positions is the same. The phase relation between the voltages is, however, effected directly by the angular position of the pick-up unit, so that as this unit is turned angularly, the phase of the output voltage of the pick-up is correspondingly varied. This property of change in phase with change in angular position of the pick-up is used to provide the necessary information for determining the position of the unbalanced weight.

To obtain a reference frequency voltage while at the same time avoiding any generator mechanically attached to the rotor, we employ a photocell receiving light reflected from the rotor that is being balanced, said rotor having a part, e.g. one half, of its surface highly polished and the remainder not polished, a suitable light source being employed for directing light upon the rotor surface for reflection to the photocell. Thus, the output of the photocell is caused to change cyclically at rotor frequency, which is also the output frequency of the electromagnetic pick-up unit.

In performing the balancing operation, the output voltage of the pick-up unit is phased against the output voltage of the photocell, as by use of a suitable meter or cathode ray oscillograph. The phase of the pick-up unit output is adjusted by changing the angular position thereof, so that the output of the pick-up is caused to combine with the photocell output so that the meter of oscillograph will show when the phase angle between the two outputs is either zero or 180°. The angular position of the pick-up unit to give this phase relation serves to determine the angular position of the unbalanced weight with respect to the non-reflecting or unpolished portion of the rotor, whereas the magnitude of the pick-up output is a measure of the magnitude of the unbalanced weight, so that with both factors known, i.e., position and magnitude of the unbalanced weight, the rotor can be readily balanced by removing the indicated amount of material from the correct point on the rotor.

In the drawings, the apparatus is shown as comprising a bedplate 1 mounted upon a suitable table or other support 2, which bedplate has upwardly and downwardly extending arms 3, 4 provided with vertical slide bearings 5, 5^1 for receiving vertical shafts 6, 6^1 provided with teeth and adapted to be raised and lowered to

any desired position within limits by means of knobs 7, 7' having pinions meshing with the teeth of shafts 6, 6'. These shafts carry angularly stationary pointers 8, 8' cooperating with degree scales 9, 9' provided on annular flanges attached to indicator discs 10, 10' turnable on shafts 6, 6'. Indicator discs 10, 10' are connected so as to turn with electromagnetic pick-up units 11, 11', respectively.

Since these pick-up units are identical, only the upper one will be described in detail, reference being made in this connection to Figs. 5, 7, 8 and 9. This unit comprises one or more permanent horseshoe magnets 12 provided with a central cylindrical depending pole 13 of soft iron on which is wound a coil 14. The horseshoe magnet 12 is adapted to cooperate with an armature 15 having the form of a soft iron ring that is arranged to be fixed upon the rotor frame 16. This armature 15 oscillates with the rotor axis under influence of rotor unbalance, so that with the central pole 13 inserted through the apertured centre of ring 15, as shown in the lower portion of Fig. 5, the ring or armature 15 is caused to move in an eccentric path around the pole 13 without actually contacting with the latter, thereby varying the flux through the central pole 13 periodically and generating a voltage in the coil 14 having a frequency that is proportional to the rotor speed.

Armature 15 is provided with a hollow cylindrical portion 17 that is threaded into a vertically adjustable rotor bearing housing 18 that carries a ball bearing 19 for receiving and supporting a rotor trunnion. The housing 18 is slidably mounted in a hollow hub portion 21 of the rotor frame 16. A thumb screw 20 is threaded into the hub portion 21 of the rotor frame 16 for urging a block 22 against the bearing housing 18 so as thereby to lock this housing in any desired vertically adjusted position within hub 21. The lower pick-up unit 11', similarly, has its armature 15' carried by a rotor bearing housing 18', having a ball bearing 19' and vertically adjustable in the hollow hub portion 21' of the rotor frame 16 by means of the thumb screw 20'.

The rotor frame 16 is of spider form, having three arms radiating from the hubs 21 and 21', each of the said arms having upper and lower horizontal members 23 and 23' and a vertical connecting member 24 positioned inwardly of the outer ends of the members 23, 23'. Spool-shaped studs 25 and 25' are fixed upon the outer end portions of horizontal members 23 and 23' for engagement in substantially triangular apertures 27, 27' provided in horizontal upper and lower supporting leaf springs 26 and 26'. The two sets of leaf springs 26, 26' each radiate outwardly from the studs 25, the springs of each set being spaced approximately 120° apart to provide a three-point support for the rotor frame 16 as will hereinafter appear. When a rotor 29 to be tested is mounted in the apparatus so that its trunnions are supported by ball bearings 19, 19', the springs 26, 26' are respectively substantially on a level with the ends of the rotor 29, so that these springs lie in the upper and lower " correction planes " of the rotor.

The rotor frame 16 is adapted to be selectively supported at either " correction plane " at will through the action of the springs 26, 26' under the control of a knob 30. This knob (see Fig. 6) is positioned adjacent the outer ends of one pair of springs 26, 26' and is fixed on the upper end of a vertical cam shaft 31 turnably supported in a casing 28 provided on bedplate 1 and having cams 32 and 32' provided thereon operating in slots 33, 33' provided in radially reciprocable follower blocks 34, 34' movable in guides in casing 28. Knob 30 is connected through a lever arm 35, link 36 and a lever arm 37 so as to turn a cam shaft 31' similar to cam shaft 31. Similarly cam shaft 31' is connected through lever arm 38, link 39'' and lever arm 40' to turn a cam shaft 31'' also similar to cam shaft 31. Thus, as knob 30 is turned to turn cam shaft 31, the similar cam shafts 31' and 31'' are likewise turned.

The radially reciprocable follower blocks 34, 34' actuated from cams 32, 32' on cam shafts 31, 31' and 31'' carry spring shackle blocks 39, 39' (Fig. 3) to which are rigidly secured the outer end portions of leaf springs 26, 26', respectively, for supporting these springs so as to extend horizontally. Spring shackle blocks 39, 39' are shown as being independently adjustable with respect to their follower blocks 34, 34' by turning nuts 40 provided on studs 41 projecting from blocks 39, 39', which nuts engage in slots provided in follower blocks 34, 34'.

Thus, by turning knob 30, the cams 32, 32' are actuated to effect a limited radial movement of springs 26 and 26', the cams being so set angularly that the three upper springs 26 move together either radially outwardly or inwardly, the same being true of the lower set of three springs 26'. When the lower set of springs 26' is moved radially outwardly, for example, the apices of slots 27' move so as firmly to engage the reduced central portions of the studs 25', as shown in Fig. 7, and so thereby firmly support the frame 16 at its lower portion corresponding to the lower " cor-

rection plane " of the rotor. The cams 32, 32^1 are so shaped and relatively positioned (see especially Fig. 4), that with knob 30 turned to one limit of its travel, the lower set of springs 26^1 are positioned at the outer limit of their radial movement to support the rotor frame 16, the upper set of springs 26 being then positioned at the inner limits of their radial movement and out of engagement with studs 25, thereby allowing free vibration of the upper rotor housing 18 and armature 15. Likewise, with knob 30 turned to the other limit of its travel, the springs 26 are at the outer limit of their movement for engaging studs 25 to support the rotor frame 16 while the springs 26^1 are at the inner limit of their movement and out of engagement with studs 25^1, as shown in Fig. 5 In an intermediate position of knob 30, springs 26 and 26^1 both engage their respective studs 25 and 25^1, as shown in Fig. 3, thereby firmly supporting the rotor frame 16 at both ends and facilitating the insertion of a rotor into this frame and its removal therefrom. Since the rotor frame is supported at all times either by the upper or lower springs 26 and 26^1, or by both, the frame is always properly centred with respect to the pick-up units 11, 11^1 and cannot become accidentally displaced. The upper and lower hub portions 21 and 21^1 are cut away at 42, 42^1 to enable free passage of the rotor trunnions into and out of the rotor frame 16.

The lower portion of cam shaft 31 carries a switch lever 43 for operating a double-pole, double-throw switch 44 (see also Fig. 7) that serves selectively to connect electromagnetic pick-up units 11, 11^1 to leads 45 of an indicating circuit, which leads extend to the mixer and attenuator 46. Thus, when the upper springs 26 are alone supporting the rotor frame 16, the lower pick-up 11^1 is electrically connected by switch 44 to leads 45, and when lower springs 26^1 alone support the rotor frame 16, the upper pick-up 11 is electrically connected by switch 44 to leads 45.

To obtain the desired reference voltage, a lamp 47 contained within a housing 48 is employed in conjunction with a photocell 50. The light from lamp 47 is directed by use of a suitable lens system, upon the underside of the rotor 29 mounted in frame 16, the reflected light from rotor 29 being received by photocell 50. The intensity of the light 47 may be varied at will as by turning the knob 49 in Fig. 1, thereby adjusting the resistance 49^1 (see Fig. 7) in the supply of lamp 47. Part of the under surface of rotor 29 is desirably polished so as to form a good reflecting surface, whilst the remainder of said under surface has little or no reflecting ability. Thus, for example, half of the under surface of rotor 29 may be polished and the other half provided with a dull surface, as by sand blasting. As rotor 29 turns, the output of photocell 50 is caused to change cyclically at rotor frequency, which is also the output frequency of the pick-up units 11 and 11^1.

The output of photocell 50 is connected by leads 51 to the mixer and attenuator 46 of the indicating circuit. This equipment comprises a transformer 52 having two primary windings connected, respectively, to leads 45 and 51, and a single secondary winding connected across a potentiometer 53. Leads 54 connect the potentiometer 53 to a band-pass filter 55, the output of which is connected by leads 56 to a suitable linear thermionic amplifier 57 of any well-known type. The output of amplifier 57 is applied by leads 58 to an indicator, such as a voltmeter 59, or a cathode ray oscillograph may be used in lieu of meter 59.

In practice, to insert a rotor into the apparatus for balancing, the knob 30 is preferably turned to its intermediate position so that both sets of springs 26, 26^1 engage their cooperating studs 25, 25^1, thereby firmly supporting both ends of the rotor frame 16. The rotor bearing housings 18, 18^1 are then moved apart, if necessary, by loosening screws 20, 20^1 so as to accommodate the rotor 29 therebetween, the rotor then being inserted from the front, as shown in Fig. 5, the rotor body passing between members 23, 23^1 and the rotor trunnions 61 entering through cut-away portions 42. The housings 18, 18^1 are then moved toward each other so that trunnions 61 are seated in bearings 19, 19^1, whereupon thumb-screws 20, 20^1 are again tightened, the rotor being now free to turn within frame 16. Air nozzles 62, 62^1 are shown in Figs. 2, 3 and 5 for controlling the speed of rotor 29, nozzle 62 serving to drive the rotor while 62^1 acts as a brake, suitable valve means (not shown) being employed for controlling the supply of air to these nozzles.

For balance-test purposes all rotors of the same size are provided with non-reflecting or dull portions of identical angular extent, the remainder of the rotor surface contacted by the light beam being uniformly polished. The pick-up scales 9, 9^1 are initially so set angularly with respect to the rotor-reflecting surface that when the unbalanced weights at the ends of the rotor coincide with a definite angular point of the rotor non-reflecting portion, or black spot, such as an end or the centre thereof, the zero reading of

scales 9, 9^1 will coincide with pointers 8, 8^1.

Thus, to obtain this initial setting, weights are placed upon the ends of rotor 29 in a common vertical plane extending through one end of the unpolished surface on the lower rotor surface. To set the scale 9 correctly, knob 30 is first turned so as to pivot the frame 16 in the lower correction plane, i.e. with springs 26^1 supporting the rotor. When the rotor has been speeded up, knob 7 is operated to move pick-up 11 down so that its pole 13 enters the central opening of armature 15, but without coil 14 touching the armature. With lamp 47 turned off, the meter 59 is now read so as to indicate the pick-up voltage only. Knob 7 is now turned to raise pick-up 11 out of cooperation with its armature 15, and the lamp 47 is turned on and knob 49 so adjusted that meter 59 reads as before, showing that the outputs of the pick-up 11 and photocell 50 as supplied through the mixer and attenuator 52 are equal. The pick-up 11 is now again lowered into cooperation with its armature 15 and with lamp 47 turned on, pick-up 11 is angularly adjusted until meter 59 reads zero, indicating that the equal outputs of the pick-up and photocell are directly out of phase.

The annular flange 65 of the indicator disc 10 is now adjusted angularly so that the zero of scale 9 coincides with the pointer 8. This is accomplished by loosening screws 64 (see Fig. 5) and bodily turning flange 65 until the zero of scale 9 thereon coincides with pointer 8. The scale 9^1 is now similarly set by pivoting the frame 16 in the upper "correction plane", equalizing the output of photocell 50 with that of lower pick-up 11^1, adjusting pick-up 11^1 till meter 59 reads zero, and then adjusting scale 9^1 to zero.

The apparatus is now set for the test balancing of rotors. To determine the unbalance of a rotor in its upper "correction plane", the rotor to be balanced is placed in frame 16, the latter then pivoted in the lower "correction plane" by turning knob 30 so that springs 26^1 engage with and support this frame 16; the output of pick-up 11 is read on meter 59 with lamp 47 unlit, whereupon pick-up 11 is raised and lamp 47 lit and its brightness varied by turning knob 49 until the output of meter 59 is the same as that previously produced by the pick-up 11. This reading of meter 59 corresponds to the magnitude of the unbalanced weight. The pick-up 11 is now lowered and turned until the meter reads zero. The indication of scale 9 now gives the angular position of the unbalanced weight at the upper end of the rotor with respect to the end of the non-reflecting portion of the rotor surface.

To determine the unbalance of the rotor in its lower "correction plane", knob 30 is turned so that the upper springs 26 support the rotor frame, i.e. so that the latter is pivoted in the upper "correction plane". The pick-up 11^1 is elevated to cooperate with its armature 15 and the output of this pick-up is read on meter 59 with lamp 47 unlit. The indication of the meter corresponds to the magnitude of the unbalanced weight. Pick-up 11^1 is now lowered and lamp 47 lit and its brightness varied by use of knob 49 until the output of meter 59 is the same as when receiving the pick-up signal. The pick-up 11^1 is now again raised and turned until the meter reads zero, whereupon the reading of scale 9^1 gives the angular position of the unbalanced weight at the lower end of the rotor with respect to the end of the non-reflecting portion of the rotor surface.

The indicated amounts of material are now removed from the rotor ends, as by drilling holes of suitable depth at the proper respective positions. A calibration curve of drill depth against voltage readings of meter 58 may be used in this connection.

While it would be very advantageous to balance the rotor perfectly in one test this ordinarily cannot be done; the considerable magnitude of the initial unbalance of an average rotor, usually necessitates two or three tests. In a typical case, the unbalance indication must be reduced from the order of two millivolts as read on meter 59 down to less than ten microvolts, —a ratio of 200 to 1. By adjusting the attenuator potentiometer 53, the signal voltage range of meter 59 is varied and this meter can be used for signals of widely varying strengths. Since the signal voltage may change in the ratio of 100 to 1 or more, changing of the meter scale by use of potentiometer 53 is essential.

In use, the apparatus of the present invention provides the extreme sensitivity required in balancing aircraft instrument gyroscope rotors without depending upon great skill in the operator conducting the test. The speed of balancing is several times faster than that possible by methods heretofore used employing highly skilled operators, and rejections of rotors due to defective rotor balancing are reduced from nearly 50% to zero because the apparatus of this invention, by largely removing the human element in making the measurements, obtains a uniform degree of accuracy in all tests made.

Although the apparatus has been shown as used for testing rotors *per se*, rotors may, if desired, be tested while in their own rotor frame. To accomplish this, the

frame 16 is replaced by a suitable ring member having plug clamps for holding the rotor frame in place while testing. The armatures 15 in such cases are adapted for removable attachment to the rotor frames.

The band-pass filter 55 serves to eliminate harmonics that would otherwise cause meter 59 to give an erroneous voltage reading in measuring magnitude, and make it impossible to phase against the reference voltage for determining position. The reference signal also has a high harmonic which the filter 55 eliminates. The pick-up and reference voltages are combined or added together by the mixer transformer 52 and then filtered by the filter 55, thereby precluding the possibility of uncompensated phase shifts in filtering. If desired, a stage of amplification may be inserted ahead of the filter 55.

The ring-type pick-up used in this invention, i.e. the pick-ups 11 and 11' employing ring shaped armatures loosely coupled to the main part of the pick-up units and without actual physical contact taking place between these parts, is a definite improvement over the gramophone type pick-up disclosed in our abovementioned Patent No. 498,899. When using the gramophone type pick-up, damping is considerable because the angular position of the displacement vector is never independent of speed in the operating range. Thus, at 200 revolutions per second a change of 20 revolutions per second results in a position-change of the displacement-vector of 2½ degrees. An even more serious difficulty of the electromagnetic pick-up is its relatively high critical speed, sometimes known as its " resonant speed ", i.e. the speed where the vibrator displacement becomes very large and the angle between the displacement vector and the disturbing force, i.e. unbalanced weight, changes very rapidly with changes in speed. This is caused partly by the phenomenon of two resonances in series, one of which is the spring-mounted frame and the other the natural frequency of the magnetic pick-up which is mechanically connected to the frame by the needle.

By using the pick-up units of the present invention, the critical speed is greatly lowered, e.g., from 115 cycles (or revolutions) per signal to 40 cycles, thereby allowing satisfactory rotor operation at much lower speeds than was possible with the gramophone type pick-up unit, and thereby also correspondingly enlarging the field of use of the apparatus.

The amplifier 57, being a linear amplifier, gives a voltage proportional to the velocity of the pick-up armature 15 since the output voltage of the pick-up is proportional to velocity. However, should it be desired to provide a voltage output from the amplifier proportional to the amplitude of displacement of the armature 15 instead of the velocity thereof, then an integrating amplifier should be substituted for the amplifier 57. This integrating amplifier would serve to integrate or add-up the voltage output of the pick-up in such a way as to supply meter 59 with a voltage dependent upon the amplitude of displacement of the armature 15, which, in turn, is a function of the rotor unbalance.

Also, in some instances it is desired to know the forces acting upon the rotor bearings due to rotor unbalance, and since these forces are proportional to acceleration of the unbalanced mass of the rotor, by employing a differentiating type of amplifier instead of amplifier 57, then the velocity signal voltage received by this amplifier from the pick-up is converted into an acceleration, or second-derivative-with-respect-to-time voltage, of the pick-up armature 15 displacement.

The filter 55 serves to eliminate all frequencies except the desired rotor frequency corresponding to that rotor speed at which it is desired to effect a balance test. It is obvious that the photocell reference voltage, when a maximum as indicated by meter 59, can be used as an indication of correct rotor speed for purposes of test.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. An improvement in or modification of apparatus for determining the unbalance of a rotor, which is the subject-matter of British Patent No. 498,899 comprising means for selectively locking the rotor against vibration at either of two points on the rotor axis, and means for measuring relative vibratory movements of the rotor axis about the point thus locked, by means of currents or voltages generated by such movements of the rotor or of a part associated therewith in a magnetic field.

2. An improvement in or modification of apparatus for determining the unbalance of a rotor which is the subject-matter of British Patent No. 498,899, wherein the rotor is so mounted as to prevent one point of its axis from vibrating during the time the vibration of another point of its axis is measured electromagnetically by means of currents or voltages generated by movement of the rotor or of a part association therewith in a magnetic field provided by a member having substantially circular symmetry about

the rotational axis of the rotor.

3. An improvement in or modification of apparatus for determining the unbalance of a rotor which is the subject-matter of British Patent No. 498,899 wherein the rotor bearing frame is so mounted that one point on the axis is locked against vibration and another point on the axis is allowed to perform conical oscillations about an axis through the locked point in a magnetic field, whereby measurements of such oscillations are made by means of the currents or voltages generated thereby.

4. Apparatus as claimed in claim 1, 2 or 3 wherein the rotor and its frame are supported in the apparatus and unbalance of the rotor serves to produce an E.M.F. in electromagnetic means comprising an armature carried by the frame and voltage-generating means disconnected from the armature.

5. Apparatus as claimed in any of claims 1 to 4 wherein a portion of the electromagnetic means is adjustable to vary the phase of the E.M.F. from said means.

6. Apparatus as claimed in any preceding claim wherein the rotor is selectively pivotally supportable within the apparatus about either of two points on the rotor axis, and the electromagnetic means is selectively responsive to vibration of the axis in the vicinity of the other point.

7. Apparatus as claimed in claim 6 wherein the rotor frame is pivotally supportable selectively by spring means about either of the two points on the rotor axis, switch means being provided for selectively connecting the electromagnetic means to an indicating circuit as the selection is effected of the pivotal support for the rotor frame.

8. Apparatus as claimed in any preceding claim wherein the turning of the whole or part of the electromagnetic means causes movement of a visual angle indicator.

9. Apparatus as claimed in any preceding claim wherein the electromagnetic means comprise a circular armature mounted adjacent to an end of the rotor and lying in the field of an inductive pick-off device so that vibration of the armature causes variation in the reluctance of the magnetic circuit, and thereby generates an E.M.F. in a winding or windings, of said inductive device.

10. Apparatus according to claim 9 wherein the inductive device has its poles so arranged that the generated E.M.F. is responsive to vibrations occurring in a plane passing through the rotor axis and not to vibration in the perpendicular plane through the rotor axis.

11. Apparatus according to claim 9 wherein the circular armature is ring-shaped, and a pole of the inductive device extends into said armature but without contacting therewith.

12. Apparatus according to claim 9 wherein the electro-magnetic means is connectible to an indicator circuit having an input transformer provided with primary windings connectible respectively with the electromagnetic means and with an alternating reference E.M.F. (of frequency proportional to the rotor speed), and filtering and amplifying means.

13. Apparatus according to claim 7 wherein the spring means comprise two sets of spring clamps that can be rapidly alternatively set to permit either end of the rotor to become the pivot of vibration due to unbalance.

14. Apparatus according to claim 13 comprising two sets each consisting of three radial spring blades, each set being mounted in a plane passing through one end of the rotor.

15. Apparatus according to claim 7, 13 or 14 wherein the spring means are selectively rendered supporting in the two planes by cam means controlled by a single knob.

16. Apparatus according to claim 14 wherein a cam serves to cause either set of three blades to be engaged with the rotor end by causing a radial pull on each blade of a set to produce engagement of bobbin-shaped studs in triangular slots in said blades.

17. Apparatus according to claim 15 or 16 wherein the cam is adapted to render the spring means supporting in both planes simultaneously.

18. Improvements in or modifications of the apparatus for determining the unbalance of a rotor, which is the subject-matter of British Patent No. 498,899 substantially as hereinbefore described with reference to the accompanying drawings.

Dated this 10th day of June, 1938.
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Leamington Spa: Printed for His Majesty's Stationery Office, by the Courier Press.—1939.

[This Drawing is a reproduction of the Original on a reduced scale.]

Fig. 1.

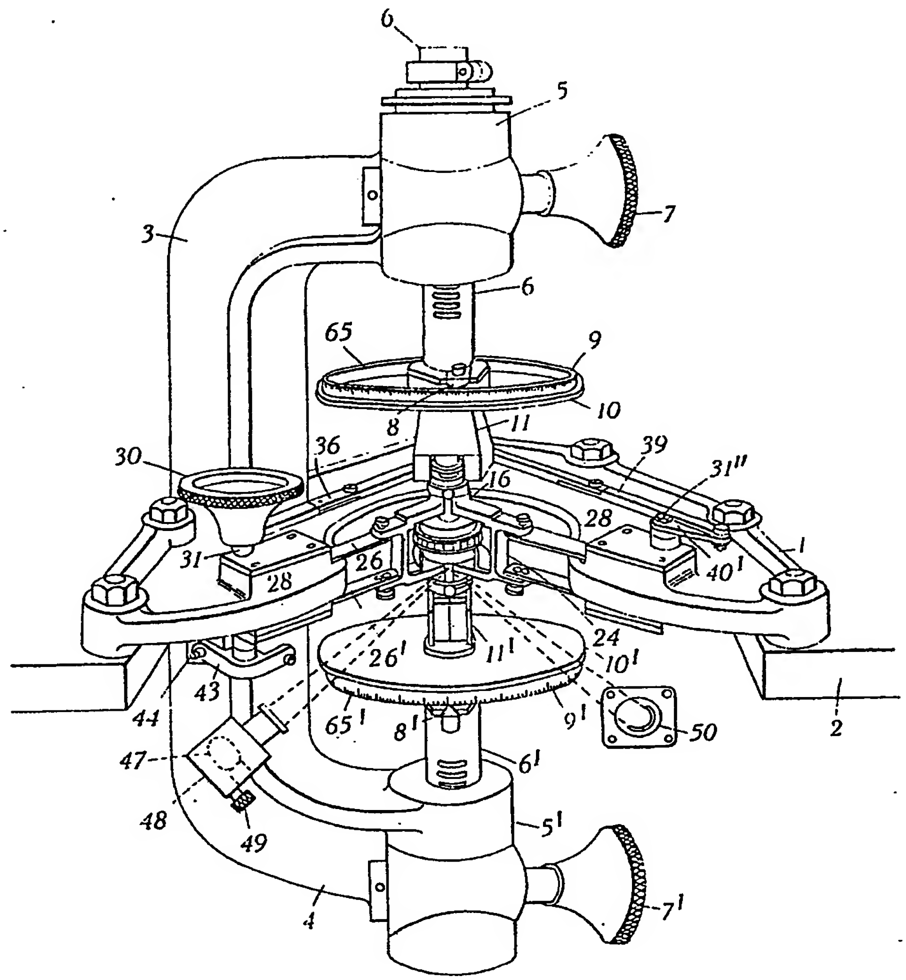


Fig. 2

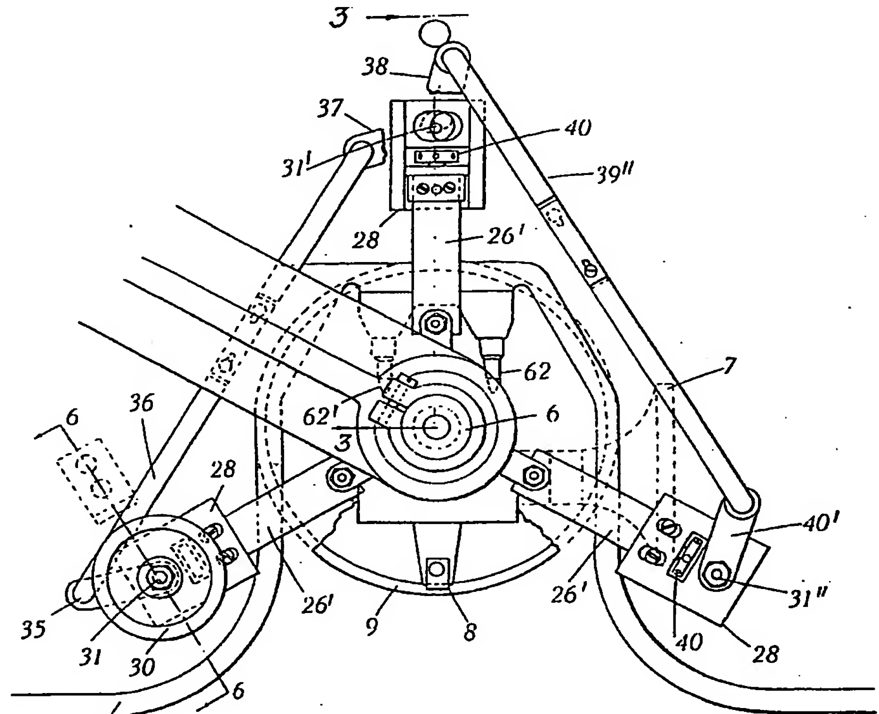
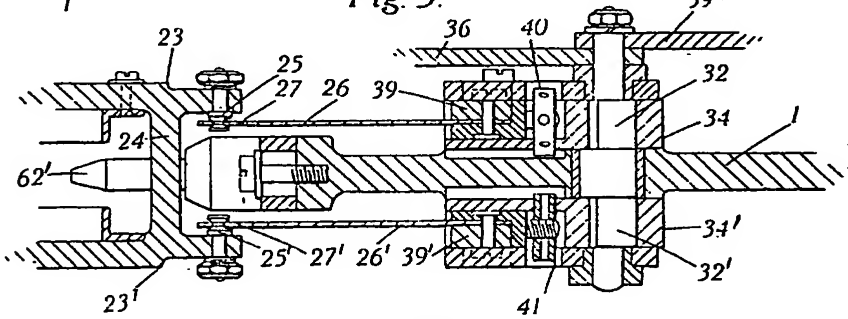


Fig. 3.



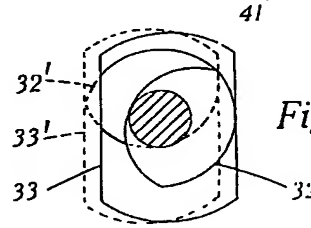


Fig 4.

1
2

[This Drawing is a reproduction of the Original on a reduced scale.]

Fig. 1.

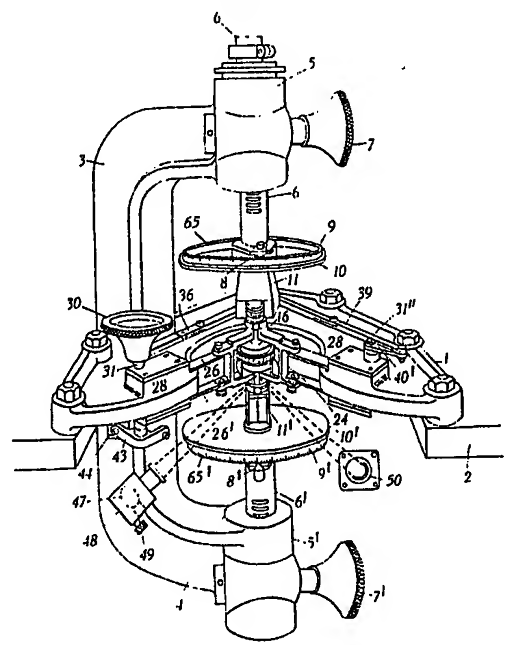


Fig. 2

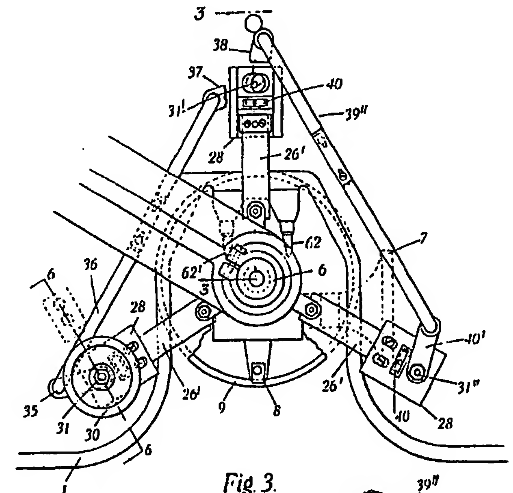
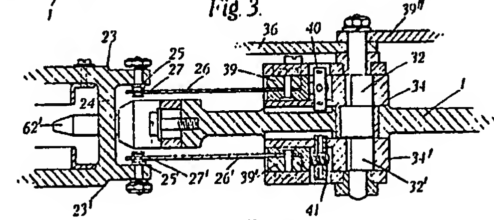


Fig. 3.



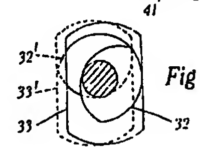


Fig 4.

[This Drawing is a full-size reproduction of the Original.]

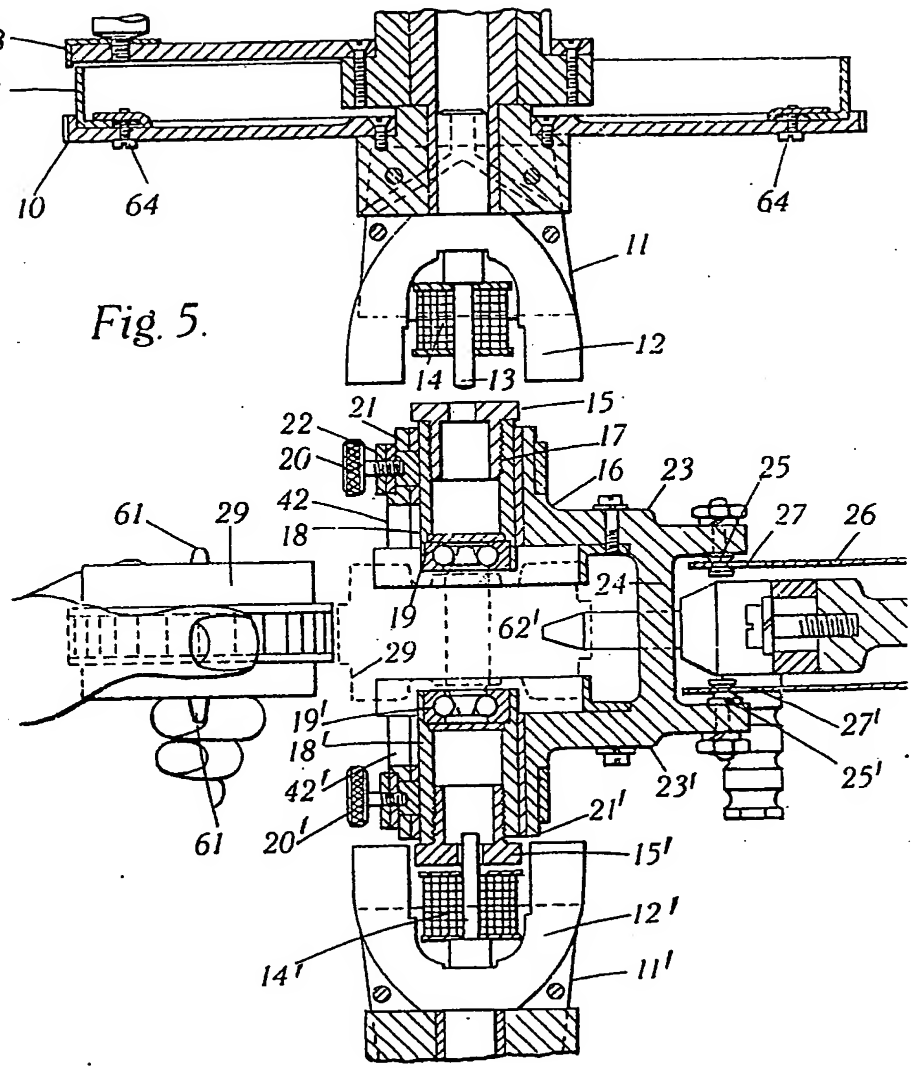


Fig. 5.

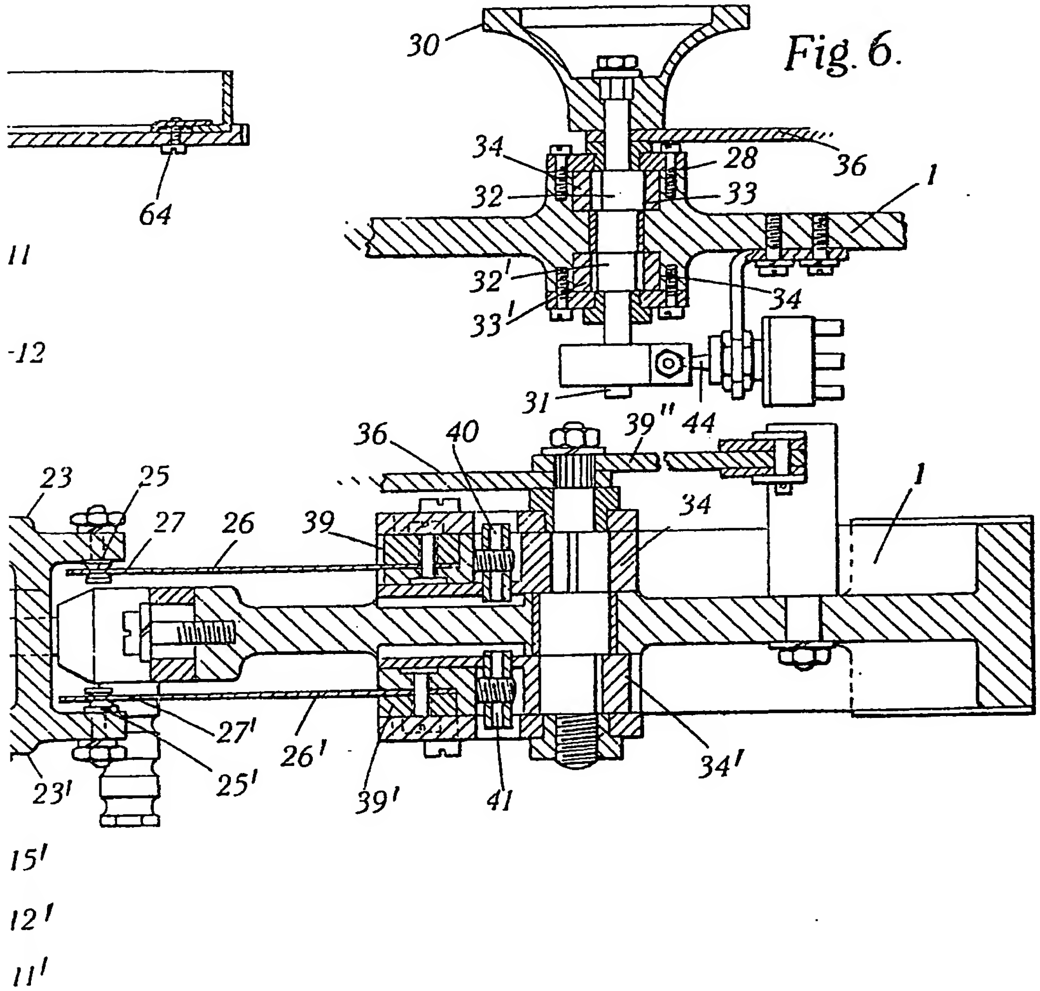

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Fig. 6.

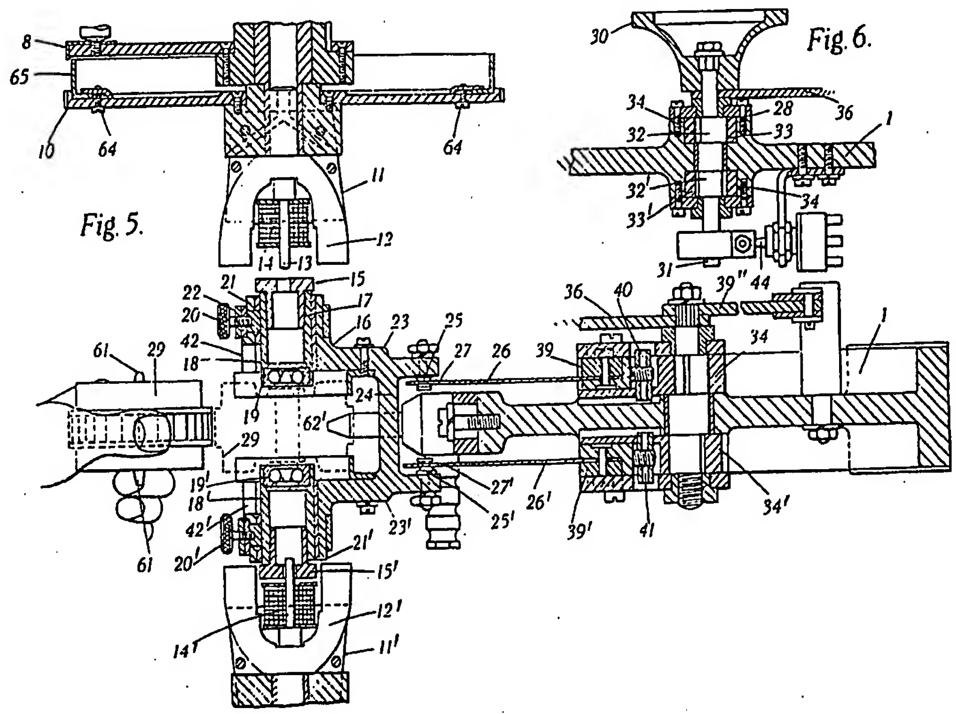

Fig. 5.

Fig. 6.

[This Drawing is a full-size reproduction of the Original.]

Fig. 7.

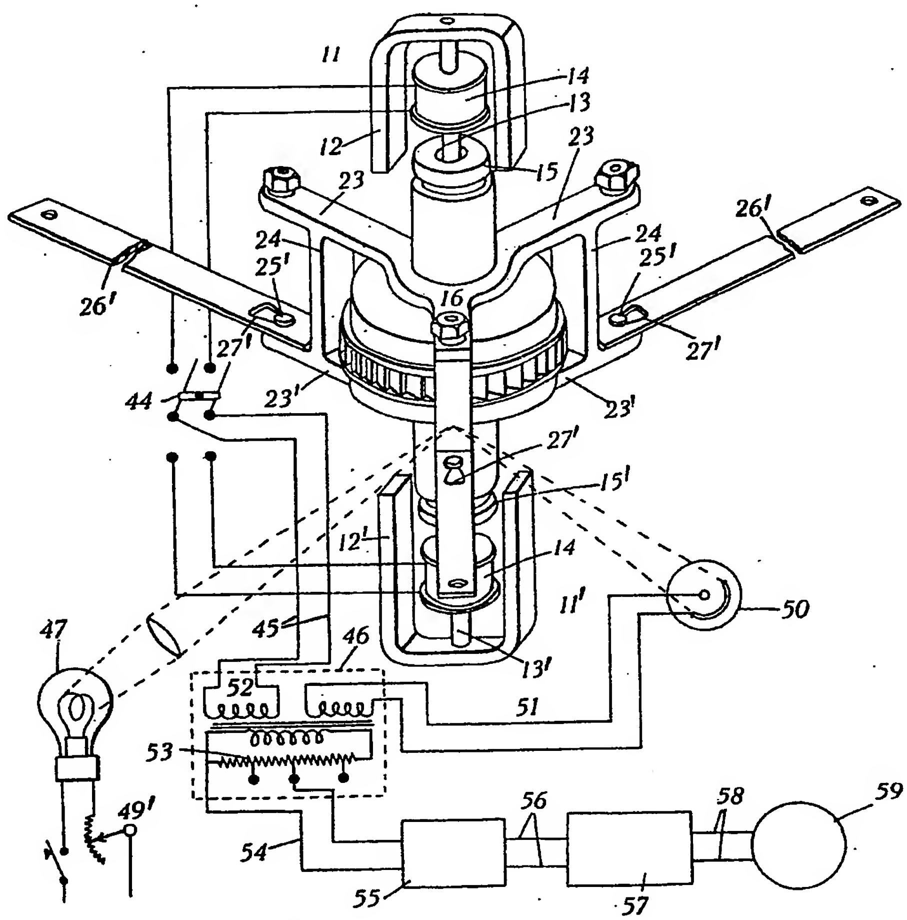

Fig. 8.

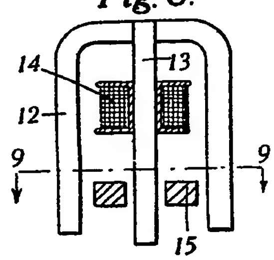

Fig. 9.